NASA
National Aeronautics and
Space Administration

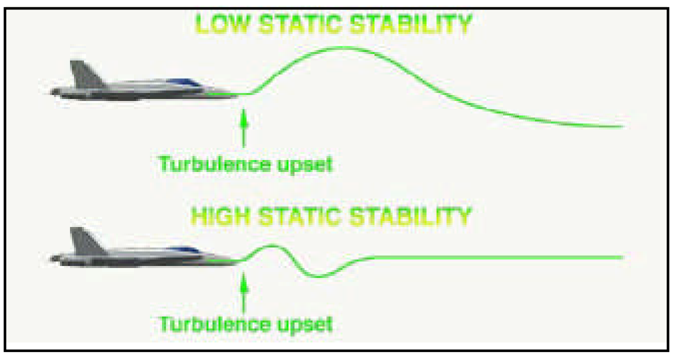
Information Summaries

IS-97/08-DFRC-WUT

Wind-Up Turn

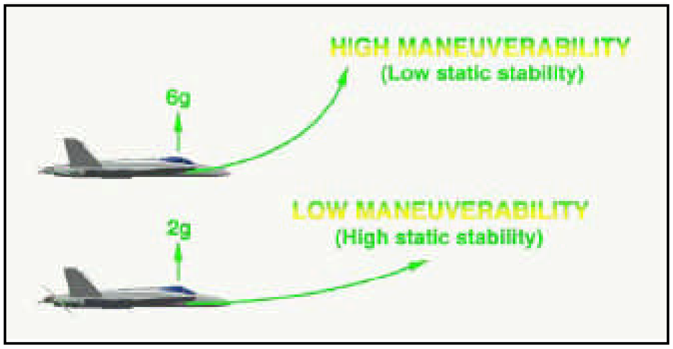
Background

Most airplanes are designed to have some amount of longitudinal stability. That is, when a stable airplane is disturbed from a trimmed flight condition it will show a tendency to return toward that same flight condition. An airplane with a high level of longitudinal stability will be more difficult to move away from the trim condition than one with low stability. Larger control deflections, and thus more pilot effort, will be required to move the flight condition away from the trim point. It will be more difficult for the pilot to maneuver. An airplane with a low level of longitudinal stability can be moved away from the trim point with small control deflections and relatively low pilot effort.

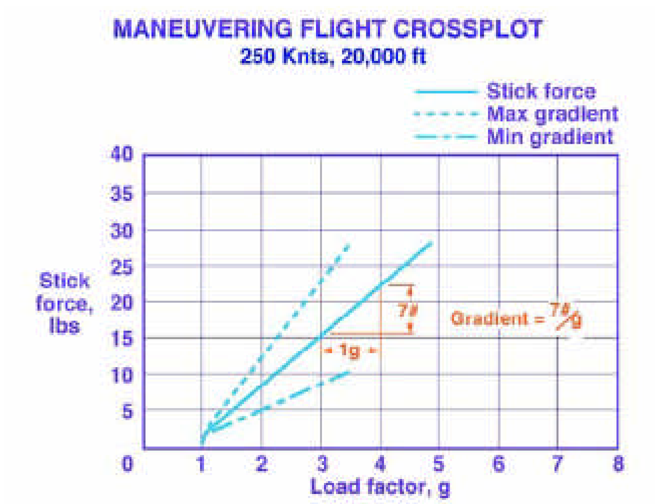


Low Static Stability

From a designers standpoint, maneuverability and stability are in direct conflict with each other. The desired level of stability will depend on the mission of the airplane. Stability may be quite high for a cargo airplane where long periods of sustained, trimmed flight through moderate turbulence are expected, and there are few requirements for rapid maneuvering. A fighter must have high maneuverability and may therefore be designed with very low longitudinal stability.



This tradeoff of stability vs maneuverability can be measured by determining the stick, or wheel, force required by the pilot to change the load factor, or g, on the airplane. The gradient of "stick force per g" is usually used as a design specification for each category of airplane. Maximum and minimum values of "stick force per g" are established for fighters, bombers, cargo carriers, or trainers. The "windup turn" is used to establish the value of "stick force per g" at a particular Mach number and airspeed.



1. Specific Objective of the Test

Determine the longitudinal stability and longitudinal maneuvering characteristics at a particular flight condition. A secondary objective is to determine the stall buffet boundaries or other stall warning features of the airplane.

2. Critical Flight Conditions

There are several conditions that will influence the value of "stick force per g", as well as the buffet and stall warning characteristics of an airplane. The important ones are:

- Airspeed
- Mach number
- Weight
- Center of gravity
- Configuration (flaps and landing gear position)

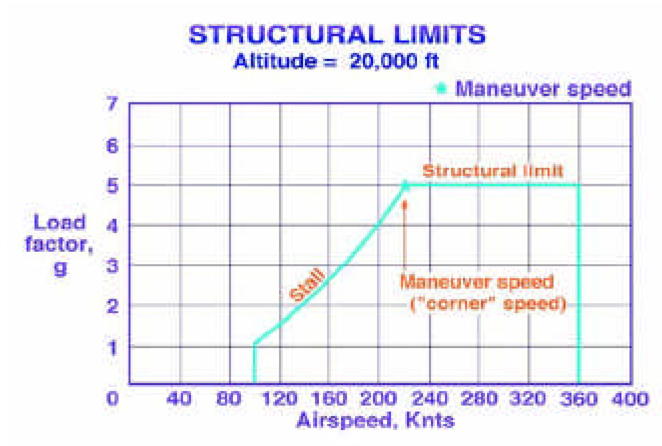
The ideal test maneuver would measure control forces and change only the load factor while holding each of these other variables at some fixed value. In this way the maneuver could be repeated for different selected values of airspeed, Mach number, etc., and the independent effects of each could be determined. The windup turn, if flown properly, will obtain the desired data for one such flight condition.

There are two limits on the maneuverability of an airplane:

1. The maximum structural capability of the wing.
This limit is associated with high airspeeds. It is usually a "placard" which the pilot must observe ("Do not exceed 5 g", for example). In some cases there is insufficient control power to reach the structural limit.

2. The maximum lift capability of the wing.
This is an aerodynamic limit referred to as "stall", and is associated with low airspeeds.

The airspeed where the structural limit is reached simultaneously with the stall is referred to as the "maneuvering speed" or "corner speed" of the airplane. It is a critical flight condition for performing windup turns since it covers the entire angle of attack range of the airplane and also the entire load or structural capability.



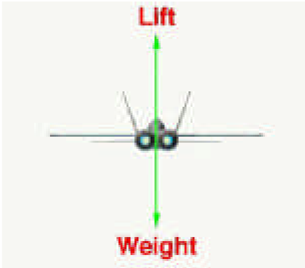
For supersonic airplanes, the transonic region can produce abrupt trim changes and severe stall buffet. This flight region is also critical for performing windup turns.

3. Required Instrumentation
The parameters usually measured and recorded during a windup turn shown in Table 1.1:

A continuous time history of these parameters is needed for the trim point, and throughout the actual windup turn maneuver. A sample rate of at least 10 data samples every second is necessary to accurately time correclated with the data samples of the other parameters. That is, we must be able to relate a particular measurement of stick force with a measurement of “g” at the same instant in time.

4. The flight test engineer will establish a table of flight condition where Windup Turns are desired. This table usually calls for particular speeds, altitudes and aircraft configurations covering the entire flight envelope of the airplane. Each maneuver is usually repeated at the same flight condition, but at different values of center of gravity position to identify the "maneuver point" of the airplane. A typical sample table of flight conditions for Windup Turns is shown in Table (1-2)

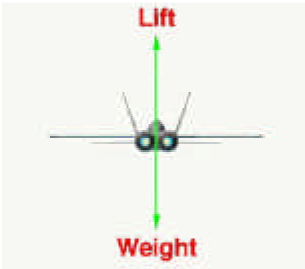
A test begins with the initial trim point. The pilot establishes the airplane in level flight at one of the desired flight conditions of speed, altitude and power setting. The pilot then uses the trim devices in the airplane's control system to allow the airplane to continue in stable, level flight, but with the pilot's hands and feet off of the controls. A short data recording is taken of this condition, usually referred to as a "trim shot".



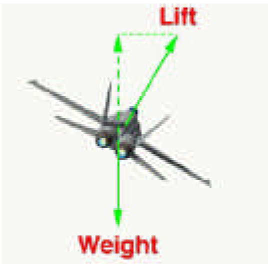
5. Description of a Windup Turn

Starting Point - A Level Turn.

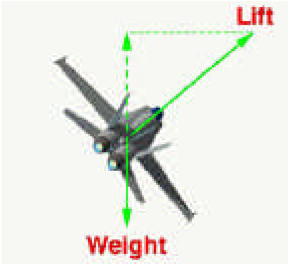
An airplane in level turning flight will experience higher values of angle of attack (and thus g), than in level flight for the same flight condition. This is because the steepness of the bank transfers some of the lift toward the direction of the turn.



The weight of the airplane remains the same and is acting toward the center of the earth. To keep the airplane from beginning to fall while in the turn the pilot will make up for this loss of vertical lift by increasing the angle of attack and thus the g.



The magnitude of the increase is related to the bank angle of the turn; the steeper the bank angle, the higher the g required to maintain the same altitude.

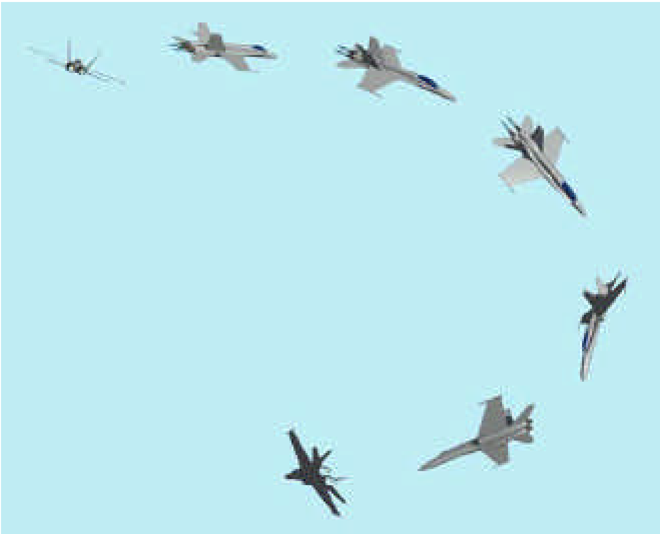


When the angle of attack increases in the turn, the drag also increases. In a level turn at moderate bank angles the pilot will compensate by adding power to balance the drag increase and thus maintain speed through the turn.

We want our test maneuver to be performed at constant speed, and we want to cover the entire angle of attack range of the airplane in a single maneuver. This implies increasing the bank angle throughout the maneuver until some very steep values are reached near the stall or g limit. To further complicate matters we also want to maintain a fixed power setting. Since we can't add power, the only way we can compensate for the increase in drag and maintain the speed is to allow the airplane to descend, or dive, during the test. The descent will be small at the beginning of the turn maneuver but will increase rather dramatically near the end.

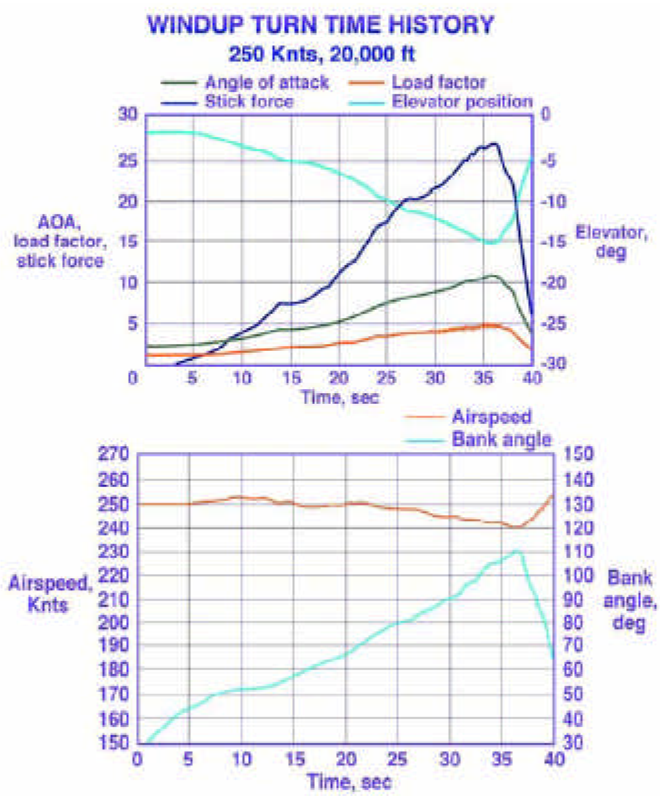
Test Maneuver - A Windup Turn

The windup turn starts from a flight condition slightly higher in altitude than the trim point. (This allows the average altitude of the maneuver to be close to the trim altitude.) The pilot begins a level turn, but allows the bank angle to continue to increase beyond that needed for a level turn. As the nose begins to drop due to the increasing bank angle, the pilot begins to slowly increase the angle of attack in a manner which will keep the speed from increasing. In a tricky balancing act, the pilot continues to increase the bank angle while simultaneously increasing the pitch stick force and angle of attack in a manner which will hold the speed constant until the airplane achieves a stall or reaches a g limit. If speed begins to slow, the pilot will increase the bank angle and slow the rate of stick force increase. If speed begins to build the pilot will shallow the bank angle and increase the rate of force increase. The ideal windup turn is a descending spiral that becomes increasingly tighter and steeper as the g is increased.



The values of bank angle required to achieve the test point are not critical to the stick force per g results of the test, but are critical to the establishment of constant speed during the test. At the end of the maneuver the airplane is usually in a very steep nose down attitude with quite high bank angles. A fighter will usually end up inverted and in a near vertical dive.

The recorded data from a Windup Turn is shown.



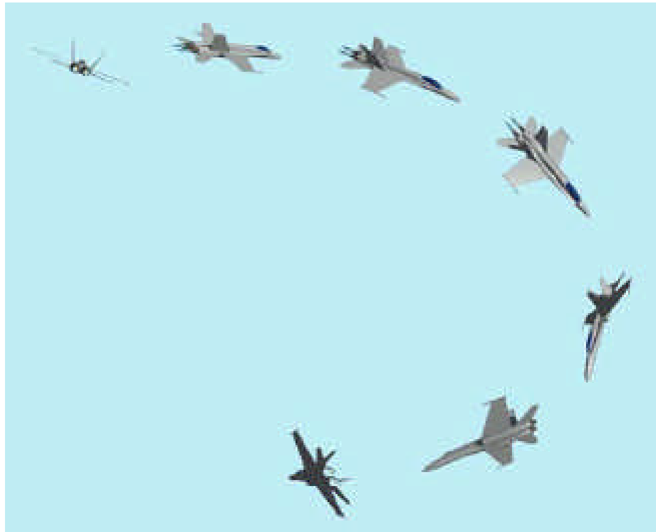
First an initial "hands-off trim shot", followed by a climb to slightly higher altitude. A smooth increase in g and angle of attack results from the smooth application of increasing stick force. Bank angle is also increased to maintain constant speed as closely as possible. As the angle of attack approaches the stall, buffet can be observed in the accelerometer (g measurement). Following the stall a recovery to level flight is accomplished.

The windup turn is a challenging task for the test pilot. It must be practiced until a smooth increase in g and stick force are achieved with little change in airspeed. It is a relatively gentle maneuver in a cargo class airplane (1 to 3 g) but more severe for a fighter (1 to 7 g).

6. Measures of Success

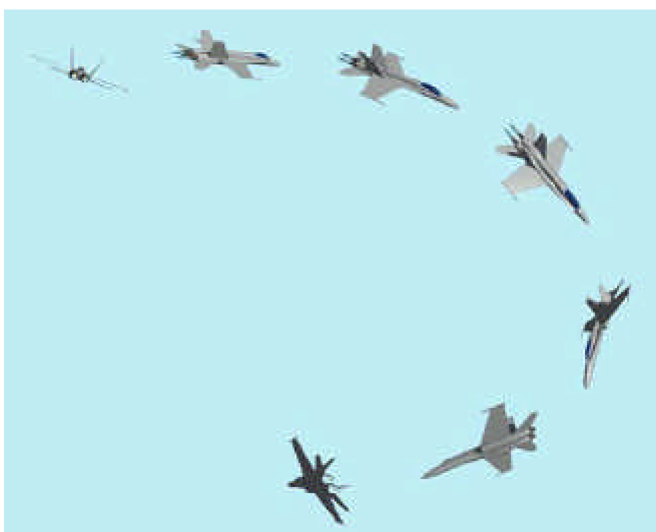
A successful windup turn will meet the following test criteria:

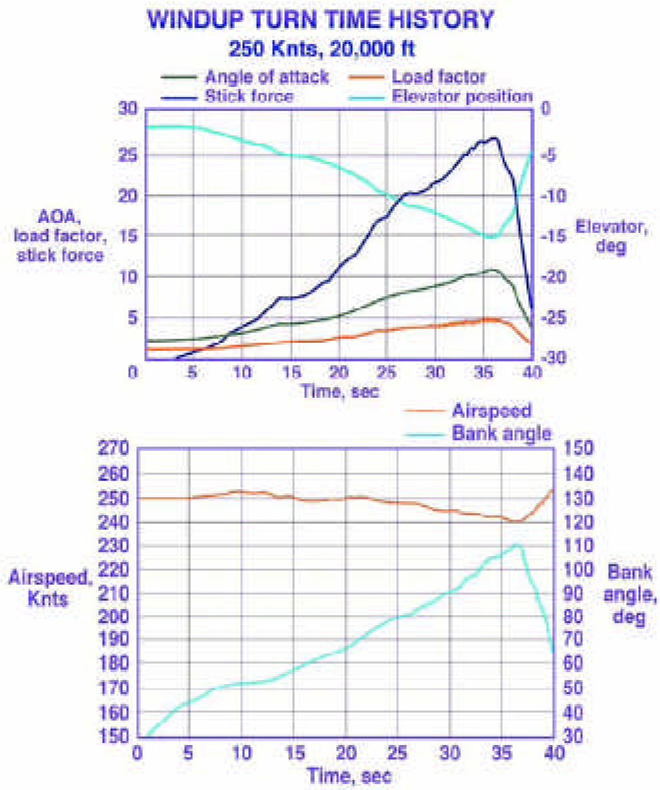
■All instrumented parameters recorded properly.



■Speed did not change more than 5 knots during the smooth portion of the maneuver, or more than 10 knots after the start of stall buffet.
■A smooth application of stick force which stays on one side of the friction band throughout the maneuver.
■A smooth increase in g throughout the maneuver with easily identified times for start of buffet.

The complete Windup Turn is shown as seen from the outside and from the inside as the data is recorded .





A repeat windup turn, or possibly several maneuvers above and below the identified flight condition, may be requested if the maneuver does not appear to follow the trends observed in other windup turns at different flight conditions

For many aircraft the stick force does not increase linearly with load factor. This "non-linearity" is usually designed into the more sophisticated flight control systems to allow fairly high force gradients near the initial trim condition (higher apparent stability) but lower force gradients as the airplane achieves higher g levels (lower apparent stability, but improved maneuverability). An example of a non-linear gradient is shown in.

Values of the force gradient must be calculated at several different locations on the curve and the resulting gradients compared to both the upper and lower boundaries of acceptability called out in the Specification.

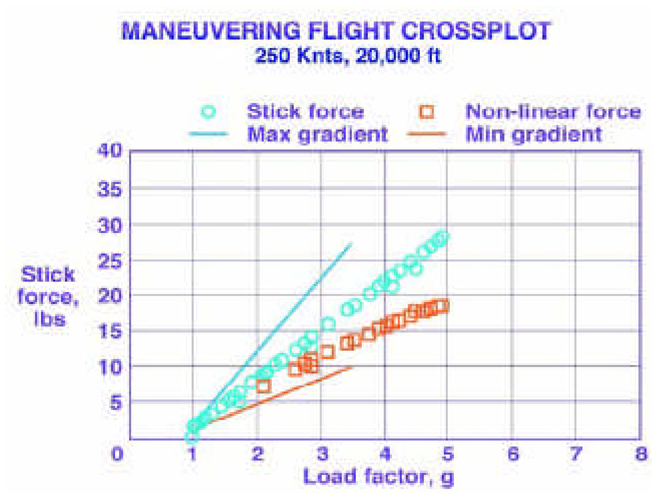


Table 1-1

Listing of Instrumentation Parameter

Parameter	**Used for**
Airspeed	Compute mach and dyn. pres.
Pressure Altitude	
Outside Air Temperature	
Normal Acceleration	"G" and buffet levels
Elevator Stick Force	Pilot effort required to maneuver
Elevator Position	Longitudinal Stability
Angle of Attack	Longitudinal Stability and stall characteristics

Table 1-2

Table of Manuevering Flight Test Conditioning

Config	Alt	Airspeed	(Mach)	cg	Limit
Clean	10000	140	.26	FWD and Aft	STALL
		200	.36		STALL
		250	.45		STALL & 5g
		300	.54		5g
	20000	200	.44		STALL
		250	.55		STALL & 5g
		300	.65		5g
		350	.75		5g
	30000	200	.54		STALL
		250	.67		STALL & 5g
		300	.79		5g
		350	.90		5g
Gear, Flaps	5000	120	.20		STALL
		140	.23		STALL
		180	.30		STALL